

DOCKET No.
HIT1P069/HSJ920030276US1

U.S. PATENT APPLICATION

FOR

SELF-PINNED CPP SENSOR USING FE/CR/FE

STRUCTURE

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SELF-PINNED CPP SENSOR USING Fe/Cr/Fe STRUCTURE

RELATED APPLICATION

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This application is related to a U.S. Patent Application filed concurrently herewith entitled "High Hc Reference Layer Structure for Self-Pinned GMR Heads" by the same inventor and assigned to a common assignee, the Patent Application being herein incorporated by reference.

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FIELD OF THE INVENTION

The present invention relates to magnetic heads, and more particularly, this invention relates to sensors having Fe/Cr/Fe structures.

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BACKGROUND OF THE INVENTION

The heart of a computer is a magnetic disk drive which includes a rotating magnetic disk, a slider that has read and write heads (also called writers and sensors), a suspension arm above the rotating disk and an actuator arm that swings the suspension arm to place the read and write heads over selected circular tracks on the rotating disk. The suspension arm biases the slider into contact with the surface of the disk when the

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disk is not rotating but, when the disk rotates, air is swirled by the rotating disk adjacent an air bearing surface (ABS) of the slider causing the slider to ride on an air bearing a slight distance from the surface of the rotating disk. When the slider rides on the air bearing the write and read heads are employed for writing magnetic impressions to and
5 reading magnetic signal fields from the rotating disk. The read and write heads are connected to processing circuitry that operates according to a computer program to implement the writing and reading functions.

In high capacity disk drives, magnetoresistive (MR) read sensors, commonly referred to as MR heads, are the prevailing read sensors because of their capability to
10 read data from a surface of a disk at greater track and linear densities than thin film inductive heads. An MR sensor detects a magnetic field through the change in the resistance of its MR sensing layer (also referred to as an "MR element") as a function of the strength and direction of the magnetic flux being sensed by the MR layer.

The conventional MR sensor operates on the basis of the anisotropic
15 magnetoresistive (AMR) effect in which an MR element resistance varies as the square of the cosine of the angle between the magnetization in the MR element and the direction of sense current flow through the MR element. Recorded data can be read from a magnetic medium because the external magnetic field from the recorded magnetic medium (the signal field) causes a change in the direction of magnetization of the MR element, which
20 in turn causes a change in resistance of the MR element and a corresponding change in the sensed current or voltage.

Another type of MR sensor is the giant magnetoresistance (GMR) sensor manifesting the GMR effect. In GMR sensors, the resistance of the GMR sensor varies as

a function of the spin-dependent transmission of the conduction electrons between ferromagnetic layers separated by a non-magnetic layer (spacer) and the accompanying spin-dependent scattering which takes place at the interface of the ferromagnetic and non-magnetic layers and within the ferromagnetic layers.

5 GMR sensors using only two layers of ferromagnetic material (e.g., Ni-Fe) separated by a layer of non-magnetic material (e.g., copper) are generally referred to as spin valve (SV) sensors. In an SV sensor, one of the ferromagnetic layers, referred to as the pinned layer (reference layer), has its magnetization typically pinned by exchange coupling with an antiferromagnetic (e.g., NiO or Fe-Mn) layer. The pinning field
10 generated by the antiferromagnetic layer should be greater than demagnetizing fields (about 200 Oe) at the operating temperature of the SV sensor (about 120° C) to ensure that the magnetization direction of the pinned layer remains fixed during the application of external fields (e.g., fields from bits recorded on the disk). The magnetization of the other ferromagnetic layer, referred to as the free layer, however, is not fixed and is free to
15 rotate in response to the field from the recorded magnetic medium (the signal field). U.S. Pat. No. 5,206,590 granted to Dieny et al., incorporated herein by reference, discloses a SV sensor operating on the basis of the GMR effect.

 An exemplary high performance read head employs a spin valve sensor for sensing the magnetic signal fields from the rotating magnetic disk. FIG. 1A shows a prior
20 art SV sensor 100 comprising a free layer (free ferromagnetic layer) 110 separated from a pinned layer (pinned ferromagnetic layer) 120 by a non-magnetic, electrically-conducting spacer layer 115. The magnetization of the pinned layer 120 is fixed by an antiferromagnetic (AFM) layer 130.

FIG. 1B shows another prior art SV sensor 150 with a flux keepered configuration. The SV sensor 150 is substantially identical to the SV sensor 100 shown in FIG. 1A except for the addition of a keeper layer 152 formed of ferromagnetic material separated from the free layer 110 by a non-magnetic spacer layer 154. The keeper layer 152 provides a flux closure path for the magnetic field from the pinned layer 120 resulting in reduced magnetostatic interaction of the pinned layer 120 with the free layer 110. U.S. Pat. No. 5,508,867 granted to Cain et al. discloses a SV sensor having a flux keepered configuration.

U.S. Pat. Appl. Pub. No. 2003/0161077 A1 to Kawawake et al. discloses a structure that uses a Fe/Cr/Fe type spin valve structure and an AFM layer as a magnetization rotation suppression layer. As disclosed therein, the Fe/Cr/Fe type spin valve provides a large change in resistance, which in turn translates into greater signal.

Another type of SV sensor is an antiparallel (AP)-pinned SV sensor. In AP-Pinned SV sensors, the pinned layer is a laminated structure of two ferromagnetic layers separated by a non-magnetic coupling layer such that the magnetizations of the two ferromagnetic layers are strongly coupled together antiferromagnetically in an antiparallel orientation. The AP-Pinned SV sensor provides improved exchange coupling of the antiferromagnetic (AFM) layer to the laminated pinned layer structure than is achieved with the pinned layer structure of the SV sensor of FIG. 1A. This improved exchange coupling increases the stability of the AP-Pinned SV sensor at high temperatures which allows the use of corrosion resistant antiferromagnetic materials such as NiO for the AFM layer.

Referring to FIG. 2, an AP-Pinned SV sensor **200** typically comprises a free layer **210** separated from a laminated AP-pinned layer structure **220** by a nonmagnetic, electrically-conducting spacer layer **215**. The magnetization of the laminated AP-pinned layer structure **220** is fixed by an AFM layer **230**. The laminated AP-pinned layer structure **220** comprises a first ferromagnetic layer **226** and a second ferromagnetic layer **222** separated by an antiparallel coupling layer (APC) **224** of nonmagnetic material. The two ferromagnetic layers **226**, **222** (FM₁ and FM₂) in the laminated AP-pinned layer structure **220** have their magnetization directions oriented antiparallel, as indicated by the arrows **227**, **223** (arrows pointing out of and into the plane of the paper respectively).

As mentioned above, AP-Pinned SV sensors typically use an AFM layer in order to pin the magnetization so that the pinned layers do not move around when the head is reading data from the disk, upon application of external magnetic fields, etc. The AFM layers are typically very thick, on the order of 150-200Å. Due to the large overall thickness, such sensors are typically not practical for use in applications where a thin head is desirable.

What is needed is a self-pinned AP-Pinned SV sensor having the signal benefits provided by Fe/Cr/Fe structures while having a smaller overall thickness.

SUMMARY OF THE INVENTION

The present invention provides the advantages described above by providing a
5 magnetic head having a free layer, an antiparallel (AP) pinned layer structure spaced
apart from the free layer, and a high coercivity structure positioned towards the AP
pinned layer structure on an opposite side thereof relative to the free layer. The high
coercivity structure pins a magnetic orientation of the AP pinned layer structure.

The AP pinned layer structure includes at least two Fe-containing pinned layers
10 having magnetic moments that are self-pinned antiparallel to each other, the pinned
layers being separated by an AP coupling layer of Cr.

In a preferred embodiment, the high coercivity structure includes a layer of
CoPtCr or other high coercivity material. The CoPtCr is preferably formed directly on
one of the Fe-containing pinned layers of the AP pinned layer structure to avoid the
15 necessity of any amorphous seed layer.

In one embodiment, the free layer includes a layer of Fe. The free layer may also
be a multi-layer stack, e.g., further including a layer of NiFe.
The structure preferably includes a spacer layer of Cr positioned between the free layer
and the AP pinned layer structure. A head as recited in claim 1, wherein the high
20 coercivity layer is formed of CoPtCr.

The head described herein may form part of a GMR head, a CPP GMR sensor, a
CPP tunnel valve sensor, etc. for use in a magnetic storage system.

Other aspects and advantages of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the present invention, as
5 well as the preferred mode of use, reference should be made to the following detailed
description read in conjunction with the accompanying drawings.

FIG. 1A is an air bearing surface view, not to scale, of a prior art spin valve (SV)
sensor.

FIG. 1B is an air bearing surface view, not to scale, of a prior art keepered SV
10 sensor.

FIG. 2 is an air bearing surface view, not to scale, of a prior art AP-Pinned SV
sensor.

FIG. 3 is a simplified drawing of a magnetic recording disk drive system.

FIG. 4 is a partial view of the slider and a merged magnetic head.

15 FIG. 5 is a partial ABS view, not to scale, of the slider taken along plane 5-5 of
FIG. 4 to show the read and write elements of the merged magnetic head.

FIG. 6 is an enlarged isometric illustration, not to scale, of the read head with a
spin valve sensor.

FIG. 7 is an ABS illustration of a CPP GMR sensor, not to scale, according to an
20 embodiment of the present invention.

FIG. 8 is an ABS illustration of a CPP tunnel valve sensor, not to scale, according
to an embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

The following description is the best embodiment presently contemplated for carrying out the present invention. This description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein.

Referring now to FIG. 3, there is shown a disk drive 300 embodying the present invention. As shown in FIG. 3, at least one rotatable magnetic disk 312 is supported on a spindle 314 and rotated by a disk drive motor 318. The magnetic recording on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk 312.

At least one slider 313 is positioned near the disk 312, each slider 313 supporting one or more magnetic read/write heads 321. More information regarding such heads 321 will be set forth hereinafter during reference to FIG. 4. As the disks rotate, slider 313 is moved radially in and out over disk surface 322 so that heads 321 may access different tracks of the disk where desired data are recorded. Each slider 313 is attached to an actuator arm 319 by means way of a suspension 315. The suspension 315 provides a slight spring force which biases slider 313 against the disk surface 322. Each actuator arm 319 is attached to an actuator means 327. The actuator means 327 as shown in FIG. 3 may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by controller 329.

During operation of the disk storage system, the rotation of disk 312 generates an air bearing between slider 313 and disk surface 322 which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of suspension 315 and supports slider 313 off and slightly above the disk surface by a small,
5 substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by control unit 329, such as access control signals and internal clock signals. Typically, control unit 329 comprises logic control circuits, storage means and a microprocessor. The control unit 329 generates control signals to control various
10 system operations such as drive motor control signals on line 323 and head position and seek control signals on line 328. The control signals on line 328 provide the desired current profiles to optimally move and position slider 313 to the desired data track on disk 312. Read and write signals are communicated to and from read/write heads 321 by way of recording channel 325.

15 The above description of a typical magnetic disk storage system, and the accompanying illustration of FIG. 3 are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

FIG. 4 is a side cross-sectional elevation view of a merged magnetic head 400,
20 which includes a write head portion 402 and a read head portion 404, the read head portion employing a dual spin valve sensor 406 of the present invention. FIG. 5 is an ABS view of FIG. 4. The spin valve sensor 406 is sandwiched between nonmagnetic electrically insulative first and second read gap layers 408 and 410, and the read gap

layers are sandwiched between ferromagnetic first and second shield layers **412** and **414**.

In response to external magnetic fields, the resistance of the spin valve sensor **406** changes. A sense current (I_s) conducted through the sensor causes these resistance changes to be manifested as potential changes. These potential changes are then

5 processed as readback signals by the processing circuitry **329** shown in FIG. 3.

The write head portion **402** of the magnetic head **400** includes a coil layer **422** sandwiched between first and second insulation layers **416** and **418**. A third insulation layer **420** may be employed for planarizing the head to eliminate ripples in the second insulation layer caused by the coil layer **422**. The first, second and third insulation layers
10 are referred to in the art as an "insulation stack". The coil layer **422** and the first, second and third insulation layers **416**, **418** and **420** are sandwiched between first and second pole piece layers **424** and **426**. The first and second pole piece layers **424** and **426** are magnetically coupled at a back gap **428** and have first and second pole tips **430** and **432** which are separated by a write gap layer **434** at the ABS. Since the second shield layer
15 **414** and the first pole piece layer **424** are a common layer this head is known as a merged head. In a piggyback head an insulation layer is located between a second shield layer and a first pole piece layer. First and second solder connections (not shown) connect leads (not shown) from the spin valve sensor **406** to leads (not shown) on the slider **313** (FIG. 3), and third and fourth solder connections (not shown) connect leads (not shown)
20 from the coil **422** to leads (not shown) on the suspension.

FIG. 6 is an enlarged isometric ABS illustration of the read head **400** shown in FIG. 4. The read head **400** includes the spin valve sensor **406**. First and second hard bias and lead layers **602** and **604** are connected to first and second side edges **606** and **608** of

the spin valve sensor. This connection is known in the art as a contiguous junction and is fully described in U.S. Pat. 5,018,037 which is incorporated by reference herein. The first hard bias and lead layers 602 include a first hard bias layer 610 and a first lead layer 612 and the second hard bias and lead layers 604 include a second hard bias layer 614 and a second lead layer 616. The hard bias layers 610 and 614 cause magnetic fields to extend longitudinally through the spin valve sensor 406 for stabilizing the magnetic domains therein. The spin valve sensor 406 and the first and second hard bias and lead layers 602 and 604 are located between the nonmagnetic electrically insulative first and second read gap layers 408 and 410. The first and second read gap layers 408 and 410 are, in turn, located between the ferromagnetic first and second shield layers 412 and 414.

The present invention provides a new sensor structure having a thinner pinned structure together with reduced current shunting to optimize dr/R . Many types of heads can use the structure described herein, and the structure is particularly adapted to a CPP GMR sensor and a CPP tunnel valve sensor. In the following description, the width of the layers (W) refers to the track width. The sensor height is in a direction into the face of the paper. Unless otherwise described, thicknesses of the individual layers are taken perpendicular to the plane of the associated layer, and are provided by way of example only and may be larger and/or smaller than those listed. Similarly, the materials listed herein are provided by way of example only, and one skilled in the art will understand that other materials may be used without straying from the spirit and scope of the present invention.

CPP GMR

FIG. 7 depicts an ABS view of a CPP GMR sensor 700 according to one embodiment. “CPP” means that the sensing current (I_s) flows from one shield to the other shield in a direction perpendicular to the plane of the layers forming the sensor 700.

As shown in FIG. 7, a first shield layer (S1) 702 is formed on a substrate (not shown). The first shield layer 702 can be of any suitable material, such as permalloy (NiFe).

Seed layers are formed on the first shield layer 702. The seed layers aid in creating the proper growth structure of the layers above them. Illustrative materials formed in a stack from the first shield layer 702 are a layer of Ta (SL1) 704 and a layer of NiFeCr (SL2) 706. Illustrative thicknesses of these materials are Ta (30Å), NiFeCr (20Å). Note that the stack of seed layers can be varied, and layers may be added or omitted based on the desired processing parameters.

A free layer (FL) 710 is formed above the seed layers 704-708. The magnetic moment of the free layer 710 is soft and so is susceptible to reorientation from external magnetic forces, such as those exerted by data on disk media. The relative motion of magnetic orientation of the free layer 710 when affected by data bits on disk media creates variations in the sensing current flowing through the sensor 700, thereby creating the signal. Preferred materials for the free layer 710 are a NiFe/Fe stack (FL1, FL2) 712, 714, but can also be formed of a CoFe/Fe stack, a CoFe/NiFe/Fe stack, etc. An illustrative thickness of the free layer 710 is about 10-40Å.

The magnetic orientation of the free layer 710 must be preset during manufacture, otherwise the orientation will be unstable and could move around at random, resulting in a “scrambled” or noisy signal. This instability is a fundamental property of soft

materials, making them susceptible to any external magnetic perturbations. Thus, the magnetic orientation of the free layer **710** should be stabilized so that when its magnetic orientation moves, it consistently moves around in a systematical manner rather than a random manner. The magnetic orientation of the free layer **710** should also be stabilized
5 so that it is less susceptible to reorientation, i.e., reversing. Usually hard magnet layers (not shown) are placed adjacent to the edges of the free layer **710** to stabilize the free layer.

A spacer layer (SP) **716** is formed above the free layer **710**. The spacer layer **716** is preferably formed of Cr. An exemplary thickness of the spacer layer **716** is about 10-
10 30Å, more preferably about 15-25Å, and ideally about 20Å.

Then an antiparallel (AP) pinned layer structure **722** is formed above the spacer layer **716**. As shown in FIG. 7, first and second AP pinned magnetic layers, (AP1) and (AP2) **724**, **726**, are separated by a thin layer of an antiparallel coupling (APC) material **728** such that the magnetic moments of the AP pinned layers **724**, **726** are self-pinned
15 antiparallel to each other. The pinned layers **724**, **726** have a property known as magnetostriction. The magnetostriction of the pinned layers **724**, **726** is very positive. The sensor **700** is also under compressive stresses because of its geometry at the ABS, and the configuration of the layer is such that it produces very large compressive stress. The combination of positive magnetostriction and compressive stress causes the pinned
20 layers **724**, **726** to develop a magnetic anisotropy that is in a perpendicular direction to the track width. This magnetic coupling through the AP coupling material **728** causes the pinned layers **724**, **726** to have antiparallel-oriented magnetizations.

In the embodiment shown in FIG. 7, the preferred magnetic orientation of the pinned layers 724, 726 is for the first pinned layer 724, into the face of the structure depicted (perpendicular to the ABS of the sensor 700), and out of the face for the second pinned layer 726. The pinned layers 724, 726 are formed of an Fe-containing material, preferably substantially pure Fe, separated by an antiparallel coupling layer 728 of Cr. Illustrative thicknesses of the first and second pinned layers 724, 726 are between about 10Å and 25Å. The Cr layer 728 can be about 5-15Å, but is preferably selected to provide a saturation field above about 10 KOe. In a preferred embodiment, each of the pinned layers 724, 726 is about 18Å with a Cr layer 728 therebetween of about 8Å.

10 In typical heads, the AP pinned layer structure 722 is stabilized by placement of an antiferromagnetic (AFM) layer above the pinned layer structure 722. The AFM layer pins the AP pinned layer structure 722 so that the pinned layers 724, 726 do not move around when disk is reading data from disk, upon application of external magnetic fields, etc. However, as mentioned above, AFM layers are very thick, typically about 150-200Å. 15 If the designer wants to fit the sensor into small gap, use of thick AFM layers is not practical.

To reduce the overall thickness of the sensor 700 while providing the desired stabilizing effect, a high coercivity layer 730 is formed above the pinned layer structure 722. The high coercivity layer 730 pins the magnetic orientation of the second pinned 20 layer 726, stabilizing the overall pinned layer structure 722.

The preferred material for the high coercivity layer 730 is CoPtCr, though other hard magnet materials can also be used. CoPtCr has a coercivity of greater than about 1000 Oe, and is sometimes used in hard disk media. This high coercivity pins the second

pinned layer 726. A preferred thickness of the high coercivity layer 730 is about 10-50Å, ideally about 30Å.

CoPtCr has a crystalline structure. Because the CoPtCr layer 730 is formed on the second pinned layer 726 of Fe, no seed layer is necessary to obtain proper physical growth of CoPtCr structure. This further reduces the thickness of the overall sensor 700.

A cap (CAP) 738 is formed above the high coercivity layer 736. Exemplary materials for the cap 738 are Ta, Ta/Ru stack, etc. An illustrative thickness of the cap 738 is 20-40Å.

A second shield layer (S2) 740 is formed above the cap 738. An insulative material 742 such as Al₂O₃ is formed on both sides of the sensor 700.

The inventor has found that the structure disclosed herein provides about ten times the magnetoresistance of a Co/Cr/Co CPP structure.

Note that in some embodiments, the first pinned layer 724 (e.g., of Fe) generates magnetoresistance with the Cr spacer layer 716. Because magnetoresistance is a function of magnetic thickness, and because the second pinned layer 726 (e.g., of Fe) and the high coercivity layer 730 above it are magnetic, it is desirable to obtain a total magnetic thickness of the second pinned layer 726 and the high coercivity layer 730 comparable to that of the first pinned layer 724. Thus, the second pinned layer 726 is preferably thinner than the first pinned layer 724 to reduce canceling of the magnetoresistive signal by the second pinned layer 726. This results in a larger net magnetoresistive signal.

One practicing the invention can determine the appropriate magnetic thickness of the layers using the following equation:

$$\text{Magnetic thickness} = M \times T$$

Equation 1

where:

M = magnetization = magnetic moment per unit volume (emu/cm³);

5 T = physical thickness (cm); and

emu = electromagnetic unit.

CPP Tunnel Valve

FIG. 8 depicts an ABS view of a CPP tunnel valve sensor 800 according to one
10 embodiment. The CPP tunnel valve sensor 800 generally has the same configuration as
the structure shown in FIG. 7, except that the spacer layer 716 is formed of a dielectric
barrier material, such as, Al₂O₃, AlO_x, MgO_x, etc. The spacer layer 716 is very thin such
that the electric current passing through the sensor 800 “tunnels” through the spacer layer
716. An illustrative thickness of the spacer layer 716 is 3-6Å.

15 While various embodiments have been described above, it should be understood
that they have been presented by way of example only, and not limitation. For example,
the structures and methodologies presented herein are generic in their application to all
MR heads, AMR heads, GMR heads, spin valve heads, etc. Thus, the breadth and scope
of a preferred embodiment should not be limited by any of the above-described
20 exemplary embodiments, but should be defined only in accordance with the following
claims and their equivalents.